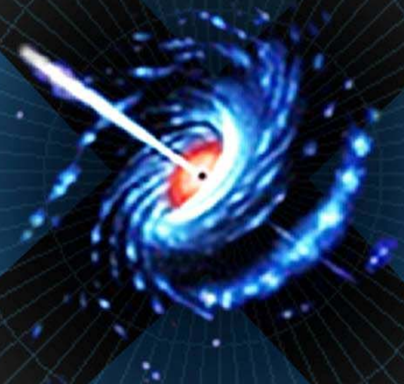
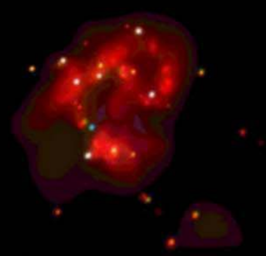
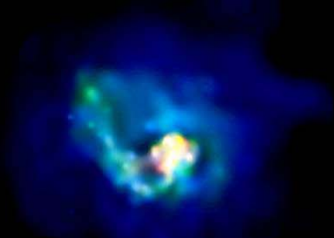
Constellation X

The Constellation X-ray Mission



Optical Metrology for the Constellation-X soft x-ray telescope





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Outline

- Introduction - why is this hard? Why is it different?
- Metrology requirements & performance summary
- Issue: fixturing
- Potential solutions to full-aperture testing

Note on optical metrology requirements

- All requirements to be shown here are derived from the overall SXT optical imaging error budget;
  - Ref: SPIE & FMA study pre-bidder's conference presentations by W. Podgorski (error budget & systems analysis) and T. Saha (optical design)
- As such, these are DERIVED requirements intended to ensure that the image error contributions from metrology are small (typically <= 10% in an rss sense) as compared to the requirements on substrates, replicated reflectors, mandrels, and optical assemblies.
  - We also are responsible for testing formed substrates as feedback to the fabrication process

Mirror comparison table – aspect ratio

	units	AstroE2	Chandra	XMM	C-X SXT reflectors		
					OAP	Prototype	Flight (20cm)
Largest mirror radius	mm	106	600	350	247.5	800	800
angular width	degree	90	360	360	56	30	30
arc length	mm	167	n/a	n/a	241.9	418.9	418.9
axial length, per reflection	mm	100	840	300	200	200	200
part diagonal	mm	194	n/a	n/a	314	464	464
substrate thickness	mm	0.155	20	0.85	0.4	0.4	0.4
aspect ratio		1253	42	353	785	1160	1160

Stiffness scales as thickness^3, so the SXT reflectors are much less stiff than all previous missions except AstroE2

HPD * areal density: mirror difficulty metric?

Table 2: HPD, Areal density, and product comparison among missions

mission	mirror material	density	thickness	areal density	Required HPD	product HPD *areal density
units		kg/m^2	mm	kg/m^2	arcsec	arcsec* kg/m^2
AstroE2	Al	2700	0.2	0.4	90	38
Chandra	Zerodur	2530	20	50.6	0.5	25
C-X SXT	Desag 263	2510	0.4	1.0	12	12
ROSAT	Zerodur	2530	20	50.6	3	152
XMM	Ni	8908	0.9	7.6	15	114

Metrology requirements & performance table

Requirements come from error budget – inputs from W. Podgorski (error budget[1])

Metrology requirement is allocated 10% of reflector derived requirements; in an root-sum-sqared budget, the metrology requirement is then 1/√10 of the reflector requirement for each error term

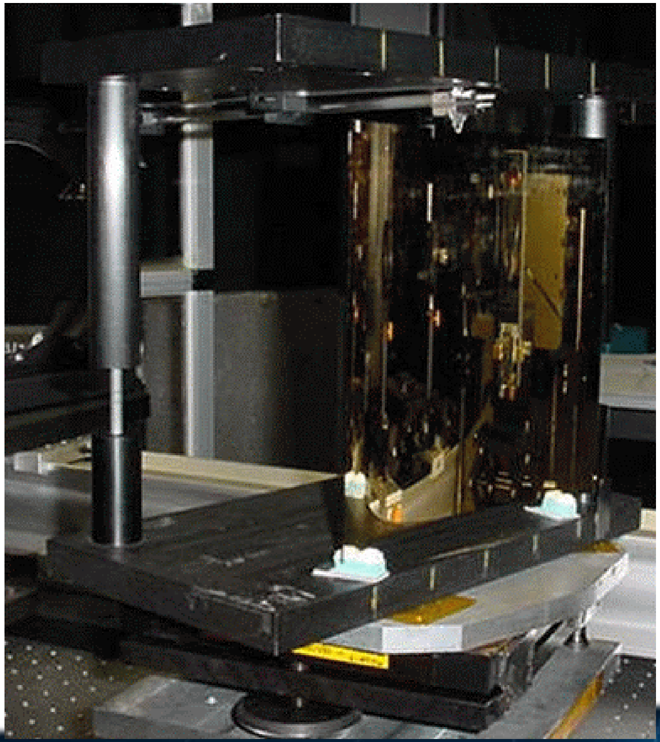
Error term	units	Reflector derived require-ment	Metrology Require-ment	Mandrel metrology: perfor-mance	Mandrel metrology: method	Substrate/Reflec-tor metrology: perfor-mance	Substrate/Reflec-tor metrology: method	note
Average radius error	um	±100	**32**	±2	CMM	tbd	nC CMM	3
Cone angle deviation	arcsec	±30	**9.5**	±5		3.2		
Delta-delta-r error, rms	arcsec	0.71	**0.2**	0.6		0.1	CDA	1
Roundness (in phase) or azimuthal figure, rms	um	5	**1.6**	0.3		(1)	nC CMM	
Axial sag error (P/V)	um	±0.07	**0.02**	±0.01	Wyko400/ 8BX	(±0.01)	Wyko400/ 8BX	2, 4
Axial slope irregularity, rms	arcsec	2.36	**0.75**	0.35		0.5		
Midfrequency error, rms	nm	8	**2.53**	0.1	Bauer200	(0.1)	Bauer200/ Wyko400	2
Microrough-ness, rms	nm	0.4	**0.13**	0.09	Micro-XAM	(0.1)	Micro-XAM	

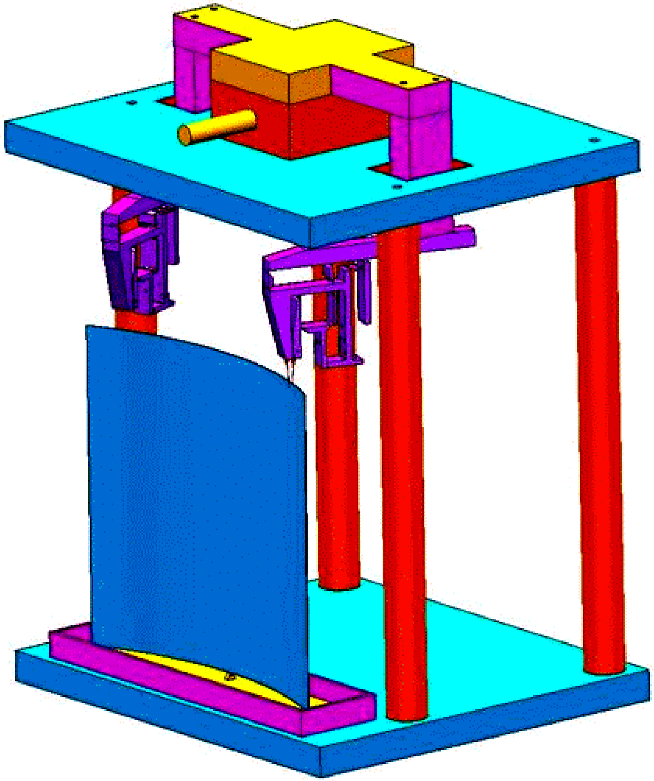
notes
1. CDA applicable to P or S substrate or replica in a housing or assembly
2. Parentheses indicate the expected value, but confirmation is incomplete on this type of part
3. nC == either non-contact or <=15mg contact force probe
4. 8BX == 8" (20cm) beam expander (built in house for 20cm axial metrology)
5. Estimate from extensive discussions inside (not formally documented)

1)W. Podgorski et al., SPIE 4168-35 (2003)

Fixturing issue for substrate/replica metrology

- Requirements for fixturing these parts for metrology are very difficult
  - Distortion must be minimized
  - Any distortions must be highly repeatable and correlated with FEM
  - Consensus is a near-kinematic mount, correlated w/ models & cross-checked
  - We are still working on this
  - Examples of mounts we are testing shown



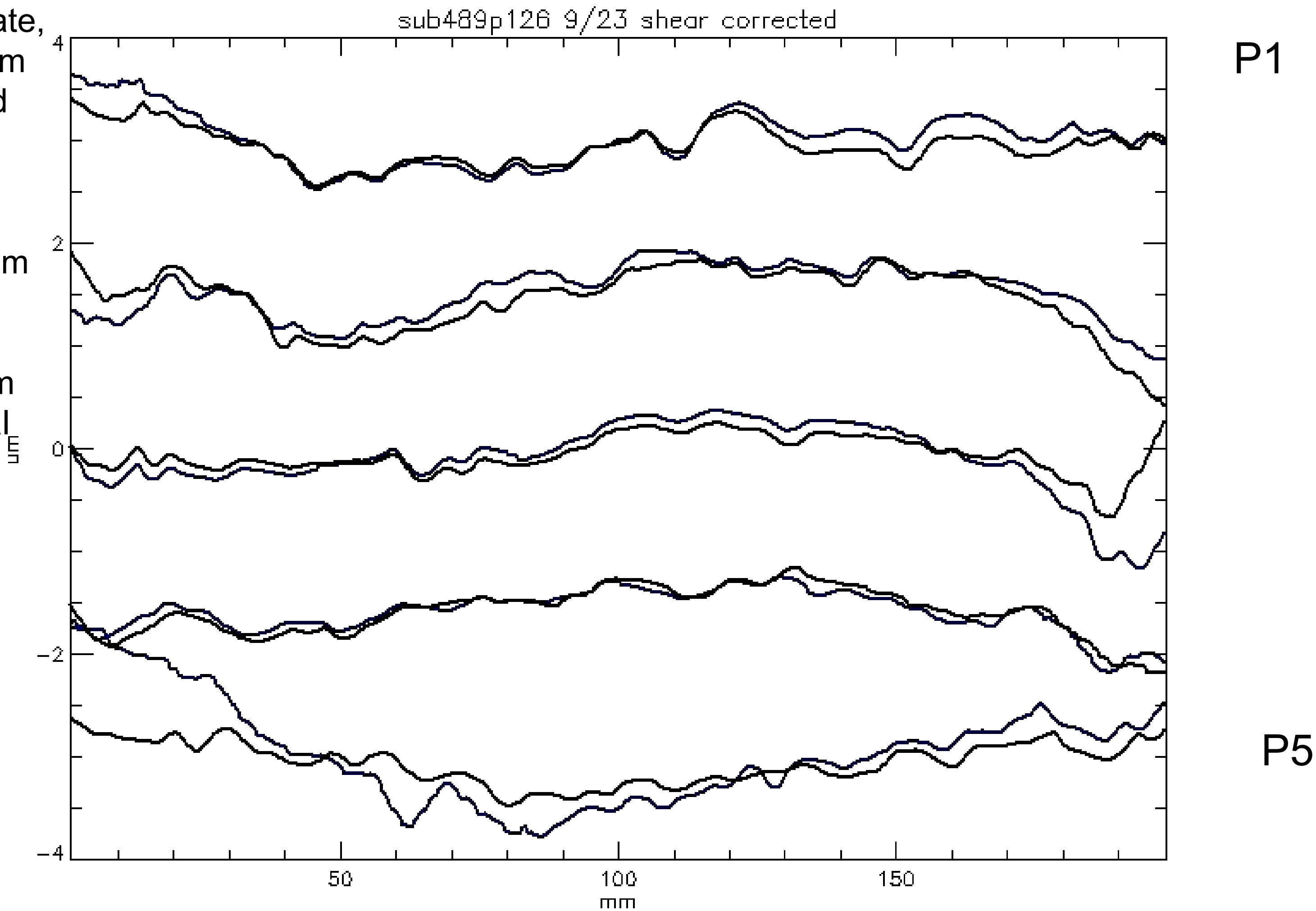


Example – axial data repeatability after removal & reinsertion into a test fixture

Part is a primary substrate, 20cm axial length, ~50cm diameter. We have used this part for extensive metrology checks

Curves are offset by 2 μm for clarity

P1/P5 are ~1/2 way from center to each azimuthal edge



9/22 & 9/23 data with shear corrected (no polynomial removal)

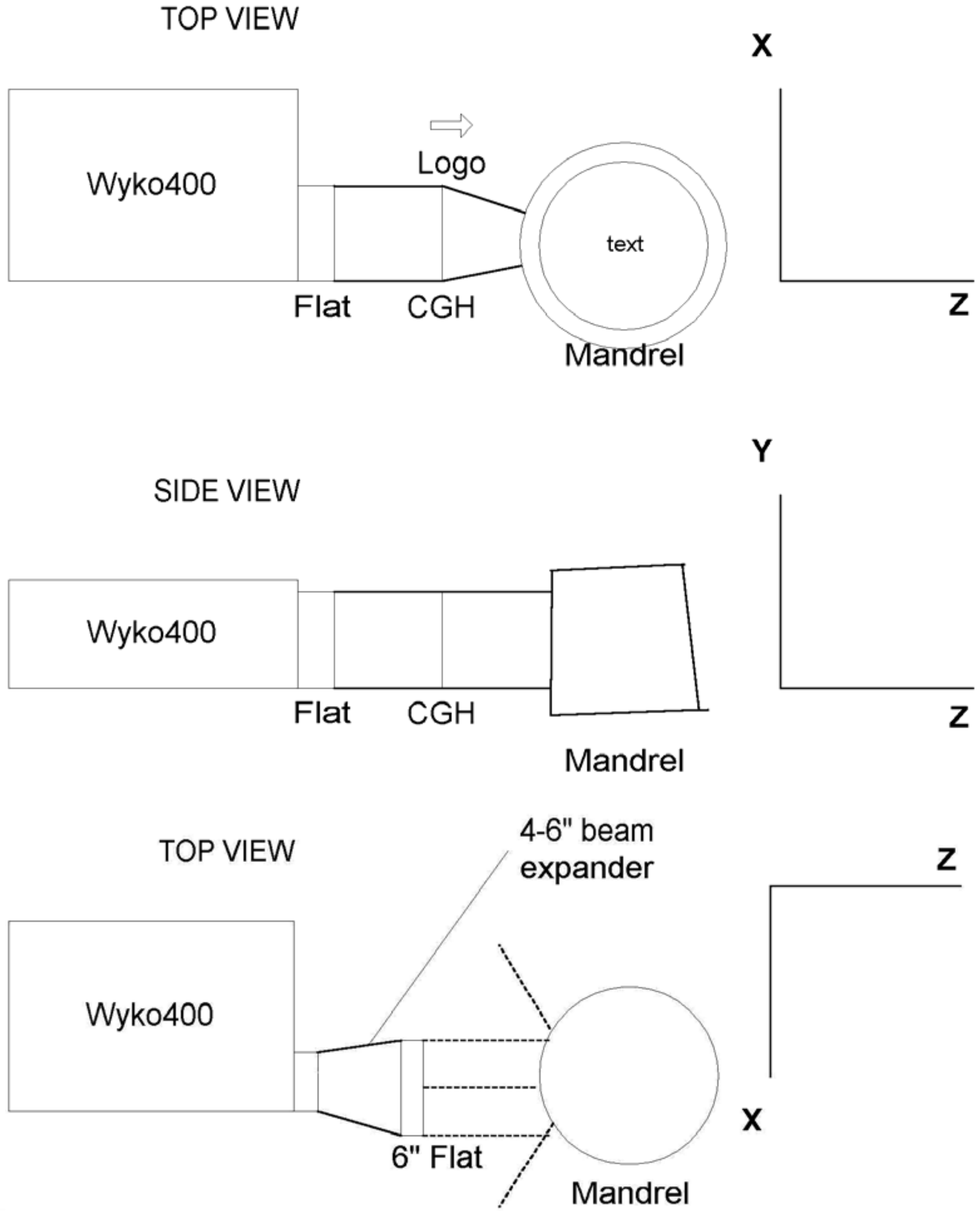
Full aperture testing

- It's been clear for some time that the current axial profiling, while useful, is not sufficient as a metrology tool
  - Still allows $\Delta\Delta R$ errors
  - Not enough area of the part covered to really supply all of the required feedback to the fabrication process
- Several potential solutions are being studied
  - Computer-generated hologram (CGH) based interferometry
  - Rapid, custom coordinate measuring machine
  - Other interferometry methods
- Example of CGH data (AstroE-scale replica) shown here

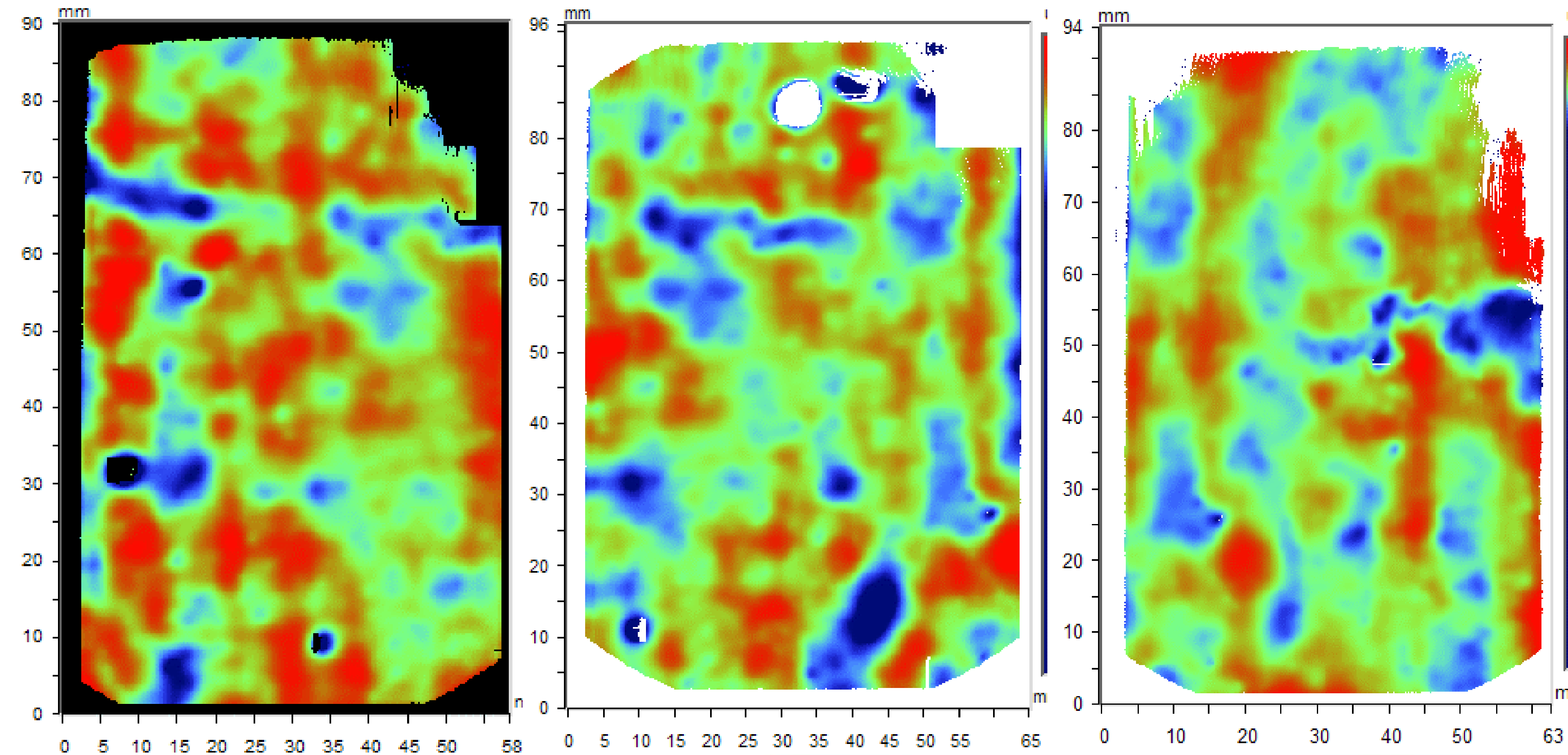
Different layouts for axial profiling of mandrels and replicas

Top: CGH cylinder/cone wave layout

Bottom: Plane wave interferometer layout



Composite (but w/ 15 Zernike's removed) – high order figure error – good correlation is evident



Example CGH data – 1 of 3 on AstroE scale substrate Sub229S-130

Measurement Parameters

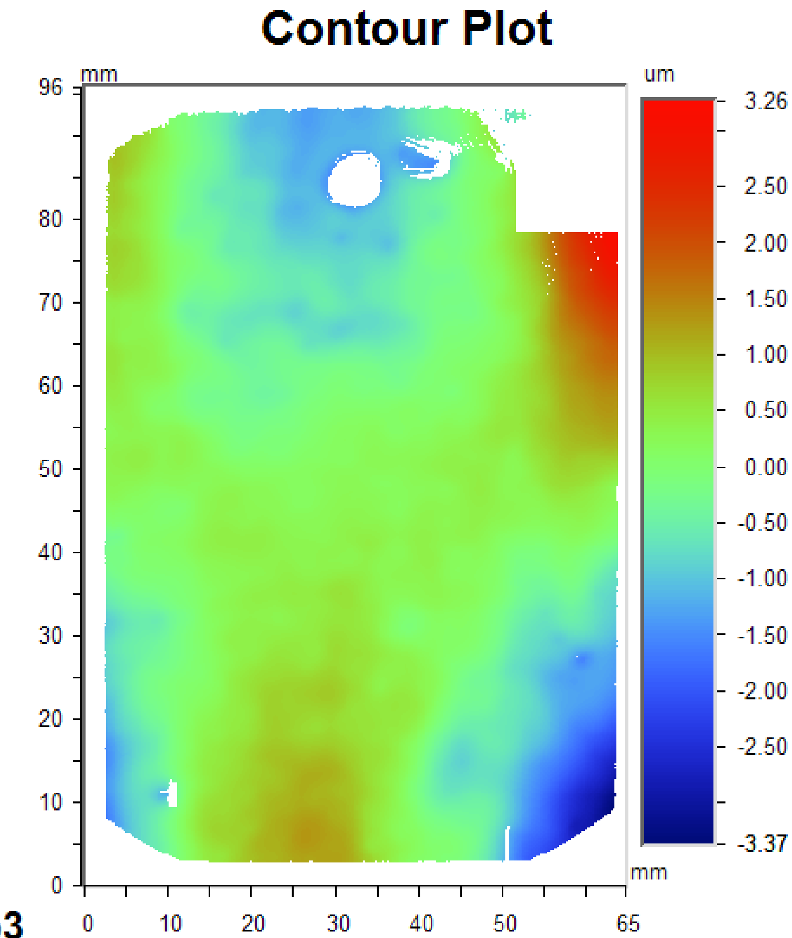
File:	Sub_229S-130_031023p_P3
Wavelength	632.80 nm
Wedge	0.50
X/YSize	373 X 473
Pixel size	174.05 um
Date	10/22/2003
Time	15:02:01
Averages	4

Analysis Results

Ra	562.860 nm
Rms	746.535 nm
20 Pt. PV	6.075 um
2 Pt. PV	6.63 um

Analysis Parameters

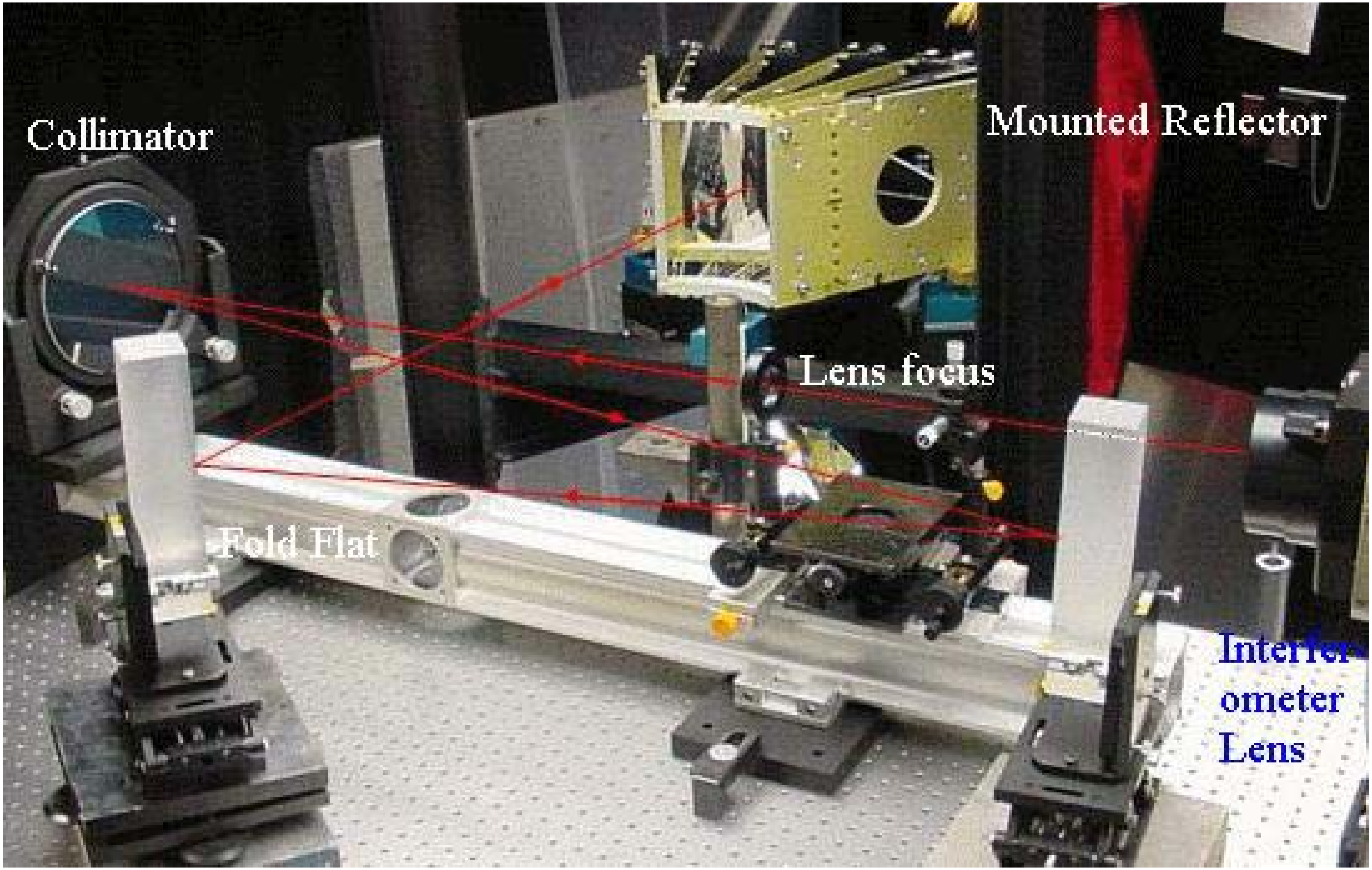
Terms	None
Masks:	
Filtering	None
Data Restore	No
Valid Points	147661



Title: sub229s130 ctrd @p3
Note: w/ cone CGH

Axial is vertical direction (mm), horizontal is ~25 degrees wide (out of 54)
3 overlapping images map the full width and 90% of the height of this 100mm long optic

In-situ axial figure station



We would prefer to use a (larger, custom) CGH here and get close to full width and as long
An axial view as CGH fabrication allows; this shows current interferometer steup for profiles only

CMM-based methods of mapping reflectors

- We are piloting this work using
  - GSFC's high precision, slow (manual) CMM
  - SAO's commercial (lower precision) automated CMM
- These are Cartesian and therefore not ideally suited to mapping conical parts. We are procuring a conical CMM, either non-contact or very low contact force
- Example data on an AstroE scale replica (mm/degrees):

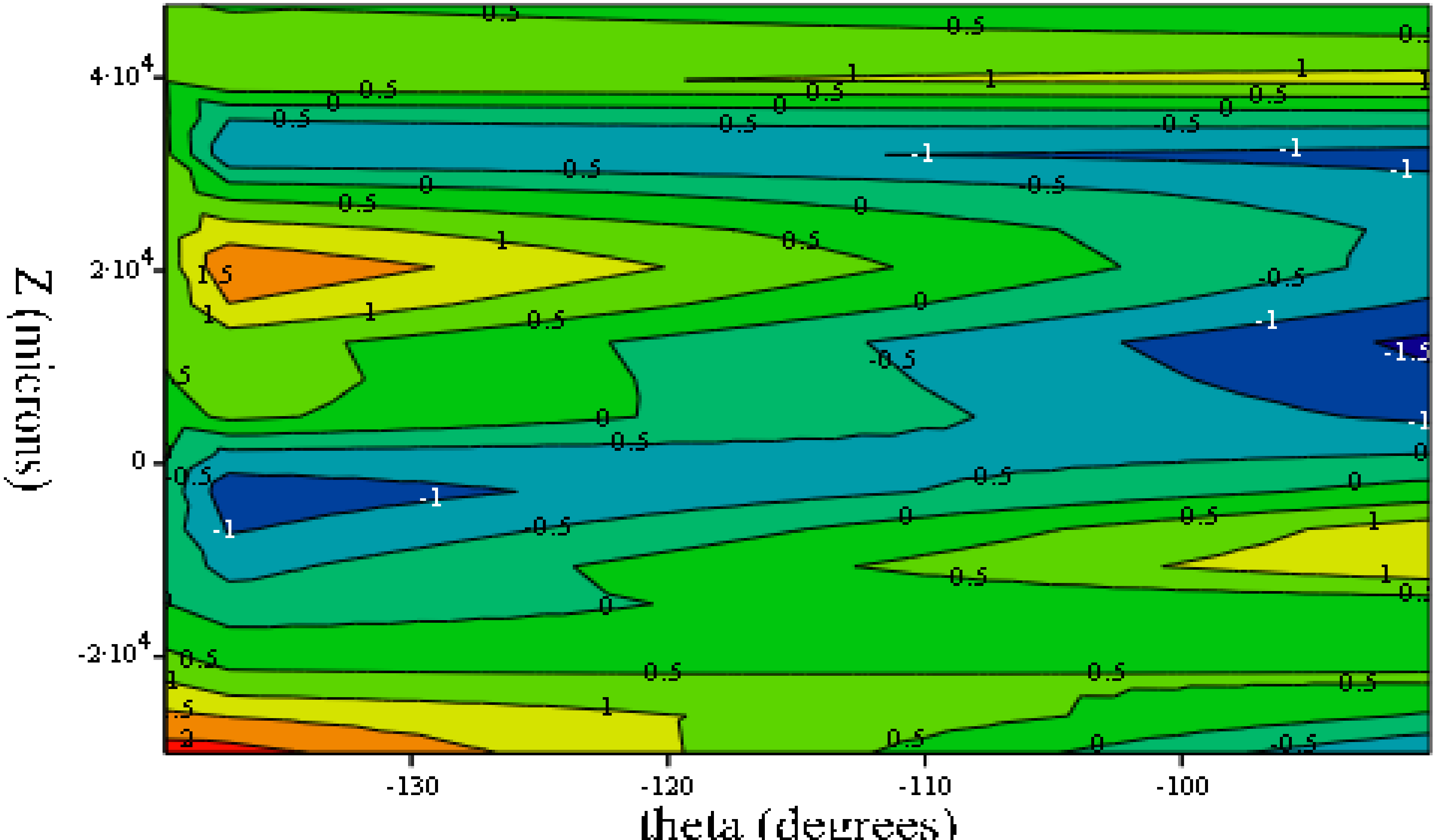
FITCONE VERSION 1.2

Fitted cone and alignment parameters

axis x-displacement:	0.917130	} misalignments (mm)
axis y-displacement:	1.995858	
cone radius at z=0 plane:	116.032083	} basic shape data
semi-cone angle (degrees):	1.102333	
cone axis tilt about x (degrees):	-0.001196	} rotation errors
cone axis tilt about y (degrees):	-0.284301	
rms deviation from best fit cone:	0.000958	} < 1 micron residual

Map of radial errors from best fit cone on AstroE replica

Replica 229s100; Rms=0.964 micron



Best cone fit to CMM data is 1.1°cone angle

(θ, z, ddr)

Summary

- The SXT reflectors have tight requirements relative to their stiffness; this places extra constraints on the metrology
- Mandrel metrology is well in hand
- Axial metrology on substrates & replicas is also in good shape
  - We are still working on the best fixturing method for substrates and replicas
- Midfrequency and microroughness correlate with the axial data
- Microroughness has been confirmed by x-ray scattering
- We are exploring different methods of mapping the substrates and reflectors to get more information both for the production process and the alignment process
  - We hope that a combination of normal incidence interferometry and CMM work will allow determination of shape, figure, and midfrequency errors

Reference: D. A. Content, D. Colella, C. Fleetwood, T. Hadjimichael, T. Saha, G. Wright, W. Zhang, "Optical metrology for the segmented optics on the Constellation-X soft x-ray telescope," Proc. SPIE [5168-23] (2003).